Analysis of mixed characteristics and influencing factors of mixing box

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Abstract. This granular mixed box device is a specialized equipment that can achieve controllable concentration and uniform mixing, calibration of particle mass concentration measurement instruments can be realized by combining with particle standard devices. Therefore, developing and ensuring the uniformity and stability of particle concentration in the mixing box is crucial for measurement and calibration. This article explores three factors that affect the characteristics of the particulate matter (inlet angle of mixing box, the dilution section angle and the diffusion section length). We fond the optimization parameters through a combination of computer simulation and experimental verification. The results show that a best mixing effect was achieved when the angle of the inlet angle of the mixed box was 45°, the diluted section angle was 80°, the length of the diffusion section was 300 mm. and the mixed performance under this condition can simultaneously meet the requirements of calibration for PM10 and PM2.5 dust instruments under low concentration.

Keywords: Particulate Matter, Mixed Box, Mixed Characteristics, Simulation, Verification.

1 Introduction

Particle matter is widely used in agriculture, food processing industry, drug production, metallurgy, and concrete manufacturing, and has become an important indicator for evaluating the production environment. Particle movement, mixing quality between different particles, and particle to air mixing quality have a very important impact on the quality of industrial products, so the mixing of particles and particles or the mixing of particles and gases has become a key issue in industrial research. At present, some scholars have conducted research on the shape and structure of particle mixing boxes to determine the mixing effect between particles. Ganggang Xu and others have studied the impact of cylindrical drum structure on the mixed behavior of particles. The part of the inner wall of the body drum type is divided into the benchmark layer, activity layer,

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zero -speed layer, interface layer and steady state layer, and compared the influence of rotation rate and filling ratio of cylindrical drum structure on particle reference layer velocity and active layer thickness[1]; Xiangwu Xiao conducted research on the influence of area ratio on particle mixing characteristics of rotating drum structures and conducted discrete phase model (DEM) experiments. The results showed that as the rotational speed increased and the filling degree decreased, the area ratio increased while the mixing time decreased. Instead of significant change in mixing degree, a strong negative correlation between area ratio and mixing time under different filling levels and rotational speeds[2]. Yuyun Bao used a DEM model to study the effects of blade shape, number, angle, rotational speed, and filling level on particle mixing level, flowability and particle density at the blade of a cylindrical mixing box[3-5]. Although scholars at home and abroad have conducted extensive research on gas-solid two-phase flow and particle mixing, theoretical research on the mixing of single component particles and gas in box containers is still in a blank state. Especially for the uniformity of particle concentration at the cross-section of gas-solid two-phase flow, there are currently no relevant standards or measurement indicators, and there are few reports on the influencing factors and simulation analysis of particle concentration[6-8].

Based on the above issues, this study optimized the size and structure of the mixing box using Solid Works 3D modeling tool firstly. Then a three-dimensional model flow field simulation analysis was conducted on mixing boxes of different sizes and structures based on Fluent Ansys software. We designed and validated an orthogonal experiment with three factors and three levels, including the inlet angle of the mixing box, the angle of the dilution section, and the length of the diffusion section. The flow field simulation analysis for each experimental scheme was conduct and explored the impact of the number of cutting heads on particle concentration. The optimal angle of the dilution section, the optimal length of the diffusion section, and the optimal angle of the mixing section obtained through simulation and experimental verification results.

2 Experimental method

2.1 Simulation settings

The simulation model adopts a model based on the Solid Works design. As shown in Figure 1, dust inlet, air inlet, and outlet using as boundary conditions, using velocity inlet and pressure outlet, dust inlet velocity was 6.14 m/s, hydraulic diameter was 14 mm, air inlet velocity was 90.27 m/s, hydraulic diameter was 22.4 mm, viscosity model was k-ε model. The Standard k-ε models were proposed by Launder and Spalding[9-11]. The stability, economy, and high computational accuracy of the model make it the most widely used and well-known turbulence model[12]. In this study, a DPM jet source model was used for the particulate phase, with a dust generation inlet flow rate of 1.825×10^{-8} kg/s, and the particle size was 5 μm[13].

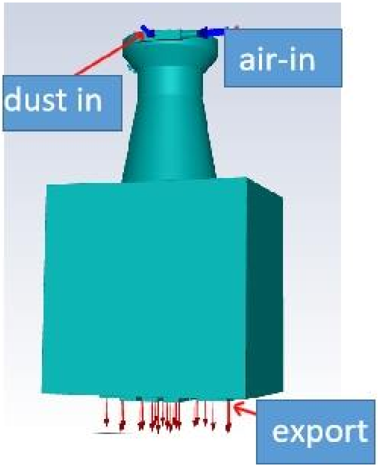


Fig. 1. The schematic diagram of mixing box

2.2 Orthogonal experiment design and analysis

At present, there are more and more research on the mixed devices and measurement calibration of particulate matter, but most of the research only pays attention to the impact of a single factor, such as the volume of the mixed box and the influence of the air intake of the mixed box. While in the actual experimental process, there are many factors that will affect the performance of particles at the same time. At this time, these factors need to be comprehensive consideration to find the optimal experimental conditions. Based on the study of predecessors, this article analyzes three factors that have an important impact on the effect of mixing the particles and mixing boxes, in order to find the optimal experimental parameters(Table 1). This article uses orthogonal experiments to analyze these three influencing factors[14-15], each factors are designed with three levels, with a total of 9 groups of experiments, as shown in table 2.

Table 1. orthogonal experimental factors and levels(3^3)

NO.	influence factor		
	A air-in angle（°）	B dilution section angle（°）	C Diffusion section length（mm）
1	45	60	300
2	50	70	500
3	55	80	700

Table 2. Orthodox experimental design table and results analysis

NO.	A	B	C	Average	standard deviation
1	1	1	1	8.37E-08	3.69E-07
2	1	2	3	1.40E-07	7.37E-07
3	1	3	2	1.12E-07	3.16E-07
4	2	1	3	1.34E-07	4.43E-07
5	2	2	2	1.07E-07	7.29E-07
6	2	3	1	1.28E-07	3.53E-07
7	3	1	2	1.35E-07	2.91E-07
8	3	2	1	1.94E-07	3.31E-07
9	3	3	3	1.99E-07	9.59E-07
k1	1.121E-07	1.175E-07	1.352E-07		
k2	1.229E-07	1.469E-07	1.181E-07		
k3	1.761E-07	1.466E-07	1.578E-07		
R	6.398E-08	2.944E-08	3.970E-08	A>C>B	A1B1C1
k1	4.738E-07	3.678E-07	3.509E-07		
k2	5.084E-07	5.990E-07	4.453E-07		
k3	5.272E-07	5.427E-07	7.133E-07		
R	5.344E-08	2.311E-07	3.624E-07		A1B1C1

2.3 Experimental verification

To verify whether the software simulation results are consistent with the experimental results, this study uses the dust device produced by Langyi Electrical and Electrical for stable dust. Through connecting to the homemade mixed box device, the verification regulations are detected in real time and recorded the value on the computer. The parameter interface is shown in Figure 2 as below:

Fig. 2. Mixed box Mixing Features Acceptance Parameter Settings

The relative error is calculated based on the formula (1):

$$\Delta_r = \left(\frac{R_B - D_B}{R_S - D_S}\right) * 100\% \quad (1)$$

Among them: Δr —sensitivity, %;
RS —calibration of dust measuring meter reading value;
RB —Reading value of dust measuring instrument;

DS —calibration of the base value of the dust test instrument;

DB —The base value of the dust measuring instrument.

When the dust is stable, start the measurement, measure it once a minute, and take the average value after 30 min continuously.

3 Experimental results

3.1 Analysis of the impact of air Inlet angle

To verify the effect of the inlet angle on the mixed effect, the value of other influencing factors was first fixed when simulation simulation, and only the angle value of the air inlet angle is changed. The length of the fixed diffusion section was fixed at 497 mm, the angle of the dilution section was 80 °, and the angle of the air inlet is changed for simulation, as shown in table 3. The simulation results were the particle motion trajectory map and the particle concentration cloud map.

Table 3. The simulation parameter table

influencing factor	Level 1	Level 2	Level 3
Intake angle	45	50	55
Diffusion section length	497	497	497
Angles of the diffusion section	80	80	80

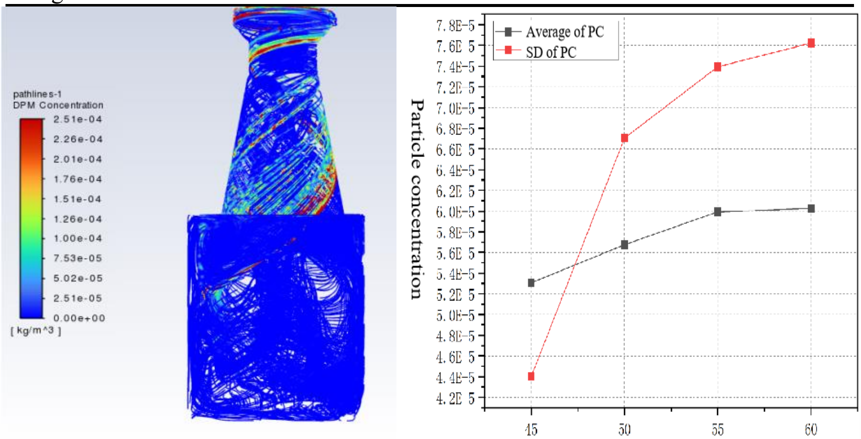


Fig. 3. Inlet anger angle to the mixed box affects the trace line cloud map and the impact of imported angles on the concentration of particles

At the same time, take the granular concentration of 15 points in the section of the middle of the mixed section when the Fluent simulation is completed, calculate the average value(average of PC) and standard deviation of the particles (SD of PC)concentration[16], then a folding diagram was draw up. It can be seen from Figure 4 that as the angle of the inlet increases, the average value and standard deviation of the particle concentration and standard deviation of the particle concentration also increase. When the angle of mouth is 45 °, the mixing situation is best.

3.2 The influence of diffusion section height

In order to verify the effects of the height of the diffusion section on the mixed box, the fixed air inlet angle was fixed on 45 °, the angle of the diffusion section was fixed on 80 °. The length of the diffusion section is changed for simulation simulation, and the simulation result was the wiring diagram of the particle movement and the particle concentration cloud diagram, as shown in Fig 5.

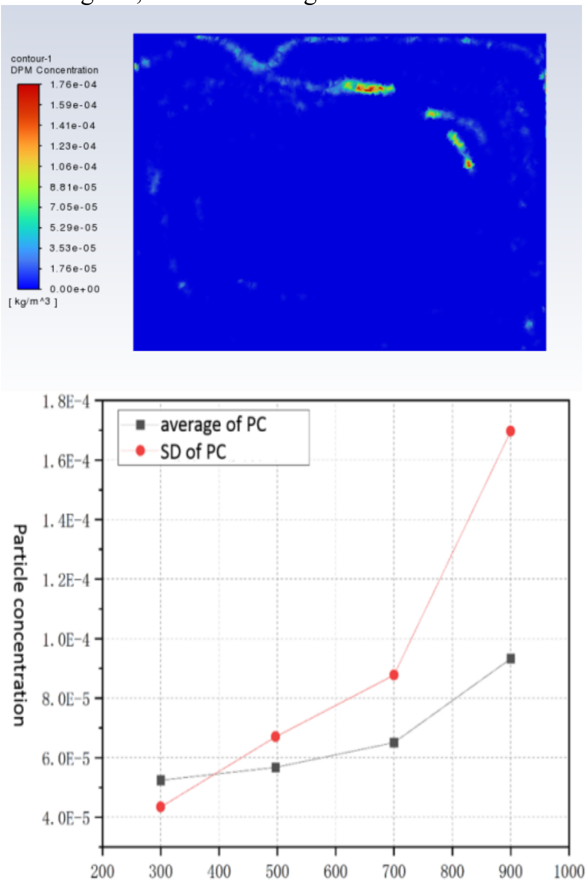
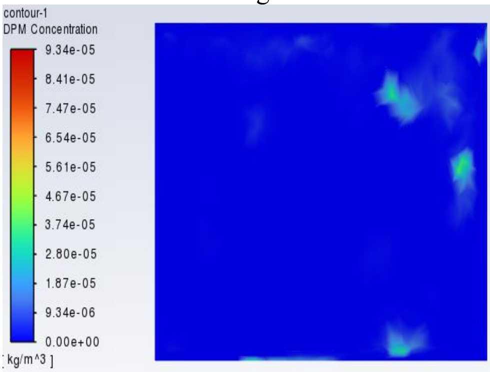


Fig. 4. Mixed segment volume score cloud chart and the influence of diffusion section height on the particle concentration

Similarly, 15 points are selected in the middle of the mixed section of the simulation result section, and the average value and standard deviation of the calculation concentration. The result is shown in Figure 6. The concentration average value and standard deviation are the largest, and the mixing effect at 300mm is the best.

3.3 The influence of the diffusion section

When exploring the influence of the diffusion section, the fixed air inlet angle was 45 °, the fixed diffusion section length was 300 mm, and the simulation simulation is performed by changing the diffusion section angle.



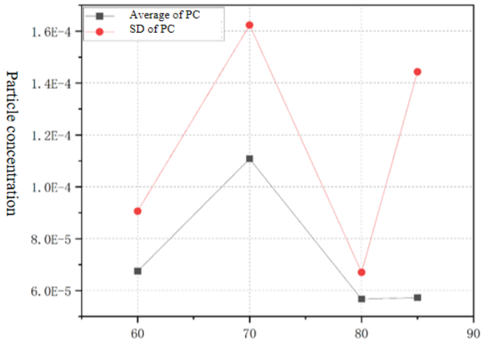


Fig. 5. Mixed segment volume score cloud chart (based on model 45-300-80 simulation results) and the angle two -pair of particle concentration effects

Similarly, 15 points were selected in the middle of the mixing section to calculate the mean concentration and standard deviation, and a line chart was obtained. It can be seen that the mixing effect is poor at angles of 70 °and 85 °, while the mixing effect is optimal at 80°.

3.4 Analysis of the orthogonal results

According to the A (diluted section height), B (middle height) and C (diffusion segment height), the average value of the particle concentration and the standard deviation of the three -level and four factor is as shown in the figure below. Calculate the corresponding K and R values according to the average and standard deviations, and the optimal combinations are found after comparison of K1, K2, and K3. The height is 50 mm, the height is 50 mm in the middle section, and the height of the diffusion section is 100 mm. The average diluted section height is the largest and has the greatest impact on the particle concentration.

3.5 Test and simulation comparison

In order to verify the reliability of the results simulated by the Fluent software, the granular mixed box was prepared based on the design drawings by Solid Works, and the experimental verification was used to use and optimized the parameter conditions. Compare, as shown in figure 6:

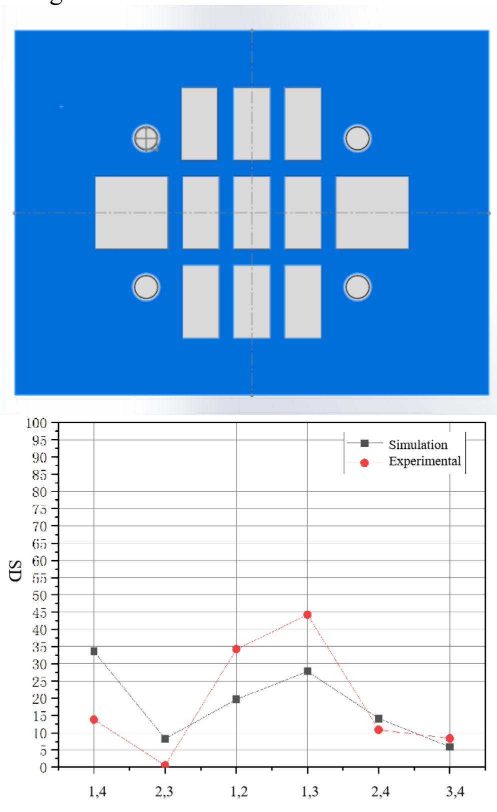


Fig. 6. Mixed Box experimental sampling port position and experiment with simulation comparison

4 Discussion

4.1 Impact factor discussion

This article studies the effects when changing the effect of mixed box structure on the mixing box. Firstly, we investigated the influence of inlet angle on the mixing effect. As changing the angle of the air inlet to 45°, 50°, 55°. When using the original angle as the reference value, the results show that the mixing effect is best when the air inlet angle is 45°. This is because when the inlet angle is 45°, particles can be better dispersed, and from the cloud image, it can be found that the flow field distribution is more uniform, and there are fewer areas with high concentrations, this result is similar to the results in the literature[17,18]. Therefore, it is considered that a 45°inlet angle is the appropriate angle. By adjusting the structure of the mixing section and changing the position and diameter of the baffle in the mixing section cuboid, the data shows that changing the baffle position from below to above and reducing the baffle position can have a good impact on mixing. For the results of the height of the diffusion section, there is a significant difference from what we expected. Under normal conditions, the higher the height of the diffusion section, the more conducive it is to the dispersion of particles. However, in a closed circular flow field, the situation is exactly the opposite. The lower the height, the more stable the flow field is, which is more conducive to making the mixing of particles more uniform. As a key position for particle mixing in the mixing box, the angle of the diffusion section is also an important factor affecting the mixing effect of particles. As the direct connection between the measurement chamber and the diffusion section, when the angle of the diffusion section is small, an unstable small vortex may form in the process, resulting in low mixing and high concentration. Therefore, the angle of this section needs to be large, but at the same time it cannot be too large, which will result in no boundary between the diffusion section and the measurement chamber. Through simulation, it was found that 80 ° is the optimal condition, which is consistent with experimental verification results. However, the results of these three factors are all obtained under other fixed conditions and cannot truly reflect the actual measurement situation. Therefore, it is necessary to verify different set values under multiple conditions, that is, our subsequent orthogonal experimental verification.

4.2 Discussion on the orthogonal results

There are many factors that affect the effects of mixed boxes of particulate matter. Among them, the angle angle, dilution section angle, diffusion section height, and the angle of diffusion section of the mixed box are considered to be the most significant factors. Therefore, these three factors were selected and 9 sets of experiments were designed by using orthogonal experimental methods under three different levels of conditions. The experimental group and the results were simulated to the 9 groups of experimental samples as shown in the table. According to the analysis methods of orthogonal experiments the K value and R values of these three influencing factors were calculated and show that among these three influencing factors, the dilution angle was the most important factor that affecting the mixed characteristics of the mixed box, followed by the diffusion section height and Angle of diffusion section. According to the orthogonal result determination method, we determined the optimal experimental combination based on the results of the R-value: A1B1C1. In this study, it happened to be the first set of experimental conditions in the validation experiment, that is, the air inlet angle was 45°, the diffusion section angle was 80°, the height of diffusion section was 300 mm. At this point, the optimal mixing characteristics can be obtained and the optimal mixing characteristics can be obtained. Compared with other methods, the mixing characteristics obtained under this optimal condition have been significantly improved, and the stability of the particles obtained after mixing is also perfect, which can meet the traceability requirements for daily calibration of dust instruments, which consistent with the particle properties described in the literature[19-21].

At the same time, it can be seen that there is a deviation between the numerical simulation values based on fluent software and the experimental measurements. The main reason for the analysis is that the dust particles used in the experiment are not standard spheres, and the model process assumes that all particles are standard spheres. This leads to the fact that in real experiments, the weight impact on the particles when they fall is not completely consistent with that of the standard sphere. Therefore, there is a certain deviation between the numerical simulation of spherical particles and the actual situation. While for the control of air inlet flow, there may be a small gap between the actual experiment and simulation due to factors such as preparation materials and environment, leading to deviation in the results. However, overall, the numerical simulation results are consistent with the experimental results.

5 Conclusion

This article focus on the structure of the mixing box, analyzes the structural characteristics of the mixing box, and analyzes three factors: inlet angle, diffusion section height, and dilution section angle. The influence of these three factors is verified through orthogonal experiments, and the optimal experimental conditions are proposed. When the inlet angle is 45 °, the diffusion section height is 300mm, and the dilution angle is 80 °, the difference between the average and standard deviation of particle concentration is the smallest, at this time the best mixing effect is achieved.

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